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I verify that the attached English translation is a true and correct translation made by me of the attached specification in the German language of International Application PCT/EP2003/008214;

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment or both under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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Electromagnetic actuating device

The present invention relates to an electromagnetic actuating device as claimed in the preamble of the main claim.

Such a device as an electromagnetic actuator, for example for use in connection with the control of valves for hydraulic or pneumatic systems or switching applications, is known in a general manner from the prior art. An armature made of magnetic material is movably guided in a magnet frame in order to carry out the essentially linear actuating movement; the magnet frame is surrounded by an electric coil device and is held in a suitably designed housing. By subjecting the coil device to electrical current, the armature is then set in the desired motion in order to carry out the actuating movement.

In such generic devices it is necessary, on account of the course of the magnetic field, for the - typically elongate - magnet frame, which comprises a core section and a yoke section, to have an intermediate section consisting of non-magnetic material between said sections so that the overall magnet frame comprises, as a rotationally symmetric arrangement, the core section, the intermediate section and the yoke section one after the other. The magnet frame is designed to be hollow-cylindrical at least in parts, in order that the correspondingly adapted, cylindrical armature element can then be guided therein along a longitudinal (movement) axis.

In terms of manufacturing technology, the sequence of core section (consisting of magnetically conductive material), intermediate section (consisting of magnetically non-conductive material) and yoke section (consisting of magnetically conductive material) is not entirely uncritical, as shown by Fig. 1 and the perspective

sectional view in Fig. 2 in order to explain the background of the present invention: The rotationally symmetric magnet frame 12, which is held in a housing 10, is as described divided into three sections (core section 14, intermediate or separating section 16 and yoke section 18) and comprises a hollow-cylindrical cavity for the guidance of an armature element 20. The yoke-side end is furthermore closed by a stop element 22 which is fixedly connected to the magnet frame 12.

As shown in Fig. 1 and Fig. 2, in the housing 10 the magnet frame 12 is also surrounded by a coil arrangement 24; a terminal 26 for contacting the coil device 24 is shown merely schematically. In Fig. 1, the cross-over area 28, which is shown as a detailed enlargement in Figs. 3 and 4, illustrates the difficulties in terms of manufacturing technology when producing the magnet frame 12.

More specifically, the object is to permanently connect the materials of the respective elements 14, 16, 18 to one another in such a way that on the one hand the arrangement can cope with the high pressures arising for example in connection with a hydraulic or pneumatic use, but on the other hand the profile of the cross-over geometry in the cross-over area 28 which is responsible for the magnetization course is not adversely affected by the manufacture. More specifically, the design of the cross-overs between core and intermediate section and between intermediate section and yoke is critical with regard to the magnetic behavior of the arrangement; there is typically a slightly conical end section in the region of the end of the core section 14 and/or of the yoke 18, in order to generate there the desired magnetization characteristics predefined by the conical shape.

However, traditional methods for manufacturing the magnet frame 12 consisting of core, intermediate section and yoke lead to undesirable deformations of the profile (of the

geometry) at the critical cross-over area 28, as shown in Fig. 3 in respect of a conventional manufacturing process. More specifically, in known manufacturing methods according to the prior art, the annular intermediate section 16 is applied to the ends of core 14 and yoke 18 by hard facing, typically by means of so-called MIG (metal inert gas) welding using a CuAl alloy as non-magnetic material to be welded on for the intermediate section 16. Beforehand, the end sections of yoke 18 and 14 have the conical profiles shown for example in Fig. 4.

However, in the case of (punctiform or droplet-based) MIG hard facing, on account of the very high arc temperatures there is the risk that the cone geometry will be significantly changed thereby, as can be seen in Fig. 3. The cone, which was originally elongate in cross section, is now wavy (in an undefined and largely random manner), so that the magnet characteristic at the critical cross-over area is affected in the region of the intermediate section 16 in a way which cannot be determined beforehand.

A further disadvantage is that, on account of the method, an increased number of cavities and pores are produced by the MIG hard facing, and these give rise to the risk of lack of sealing in the region of the intermediate section, and also to the risk of a fatigue fracture of the magnet frame.

A further disadvantage of the outlined, conventional manufacturing method is that relatively long process times of typically approx. 30 seconds are required for the hard facing process, and this in turn has a disadvantageous effect on the manufacturing time and thus on the manufacturing costs, since on the other hand, however, the penetration of heat into the welded joint is limited by the cone geometry which has to be retained, and this process time cannot be further reduced, at least not without adversely affecting the cross-over geometry, cf. Fig. 3.

A further disadvantage in terms of manufacturing outlay which is caused by the known technology is that, during the hard facing operation, adjacent component parts are adversely affected by welding sprayers, and thus additional outlay in terms of cover is required. Added to this is the fact that applied material for the area 16 has to be undercut in order to produce the cylindrical outer and inner shape, and this accordingly entails further outlay.

Finally, another disadvantage of the conventional method is that the non-magnetic additional material for the intermediate section 16 is relatively expensive in terms of wire dimensions (since the operations of roughing-down and annealing to a small diameter entail a significant outlay in terms of manufacture).

It is therefore an object of the present invention to provide a generic electromagnetic actuating device which on the one hand is improved with regard to its predefined electromagnetic properties at the cross-over areas between core and non-magnetic intermediate section and between intermediate section and yoke, and on the other hand is simplified with regard to its manufacture, in particular in terms of the outlay associated with its manufacture, and in particular allows the manufacture of electromagnetic actuating devices at a lower cost.

This object is achieved by the device having the features of the main claim and by the method as claimed in the independent method claim 7; advantageous embodiments of the invention are described in the dependent claims.

In an advantageous manner according to the invention, at least one of the cross-over areas between yoke section and intermediate section or between intermediate section and core section is produced by means of a friction welding method; the invention also comprises the case in which yoke

section and intermediate section are formed in one piece from non-magnetic material and thus only one cross-over area produced by friction welding exists.

The (surface) friction welding method according to the invention has the advantage that, by virtue of the (strong) friction, the contact surfaces heat up in such a way that especially the material for the non-magnetic intermediate section becomes plastic but does not, however, as in the case of arc welding, become fluid. Thus, by virtue of an appropriate compression force, a reliable weld can be produced at the cross-over point. Although said weld has the required high strength, at the same time it leaves unchanged the geometry predefined by the core and yoke end sections, for example the selected cone geometry, and thus the magnetic field course set thereby can be calculated and remains unchanged. By virtue of the plastic, rather pasty state of the materials of the joint, cavities and pores can moreover arise only to a very limited extent, unlike in the case of hard facing; moreover, since the effect takes place over the entire surface, the inhomogeneities of the droplet-based hard facing method are avoided.

A further advantage of this friction welding method is that, with respect to the application for the welding operation of typically approx. 10 to 15 seconds, considerably less time is required and thus the manufacturing process also becomes more rapid and efficient.

A further advantage is that the non-magnetic material for the intermediate section can now be fed and used as a hollow-cylindrical or stock material and thus in a significantly more cost-effective manner than wire material. Moreover, it has been found that a more cost-effective material quality can be used for the intermediate section as separating section.

As a result, the present invention thus provides, in a surprisingly simple manner, a manufacturing process for generic electromagnetic actuating devices which is based on the principle of friction welding and makes the manufacture much simpler and less expensive, and as a result of which magnetic properties, the quality of the cross-over point and the load properties of the resulting end product are moreover considerably improved.

In a preferred manner according to one embodiment it is provided that at least one of yoke section or core section comprises a cone shape at its end facing the intermediate section; according to the invention, this ensures that a particularly favorable magnetization course exists at the cross-over points to the intermediate section and thus the magnetic properties, on account of the teaching of the use of friction welding according to the invention, are particularly useful.

On the one hand, it is favorable to design the shape of the intermediate section in a correspondingly conical manner as a partner for the friction welding, or else to design the facing end section of the intermediate section to be flat, cylindrical (and thus non-conical); it has surprisingly been found that in this case too the friction welding leads to an extremely advantageous cross-over between the materials, which cross-over virtually does not change the original geometry.

While on the one hand it is possible and preferable to join in each case one of the connection partners (yoke section or core section) for example on either side of the annular intermediate section by virtue of the advantageous friction welding method according to the invention, and even more preferably to do this simultaneously in one common operation, it is likewise within the scope of the invention to carry this out in successive operating steps, or to limit it to one cross-over joint.

Since the present invention gives rise, in a particularly reliable and mechanically stable manner, to a cross-over between the connection partners which is low in cavities and pores, and thus the risk of lack of sealing is minimized, the present invention is particularly preferably suitable for electromagnetic actuating devices which are used in connection with hydraulic or pneumatic valves, and in particular in high-pressure applications of up to several hundred bar, as arise for example in many applications of stationary and mobile hydraulics. However, the present invention together with its advantages is not limited to such applications.

Further advantages, features and details of the present invention emerge from the following description of preferred examples of embodiments and with reference to the drawings, in which:

Fig. 1: shows a sectional view through the electromagnetic actuating device according to the present invention to illustrate the advantages of the invention compared to the prior art;

Fig. 2: shows a view analogous to Fig. 1 in a perspective direction as a three-dimensional object;

Fig. 3: shows an enlarged representation of the cross-over area 28 in Fig. 1 according to the prior art, with a cross-over geometry deformed by hard facing;

Fig. 4: shows a view analogous to Fig. 3 following the friction welding of the present invention, with a non-deformed cone shape (ideal state);

Fig. 5: shows an exploded diagram of the connection partners - core, intermediate section, yoke - according to a first embodiment of the invention, prior to joining by the friction welding method;

Fig. 6: shows a diagram analogous to Fig. 5 of a second embodiment of the invention, with a different geometry of the intermediate section; and

Fig. 7: shows a diagram of the arrangement of Figs. 5, 6 after joining by friction welding.

Based on the schematic representation described above of an electromagnetic actuating device as shown in Fig. 1, Fig. 2 and the problems of deformation of the (in this case originally conical) core and yoke geometry following application of the intermediate section 16 by hard facing, Fig. 4 shows, analogously to the diagram in Fig. 3, that as a result of the friction welding method the core-side cone geometry comprising cone section 32 and flat annular section 34 and the pure cone shape of the yoke section 18 remain virtually non-deformed and thus unchanged, and thus the originally determined magnetic properties predefined by the cone shape are fully retained.

Specifically, in the example of embodiment shown, the core 14 was set in a rotary movement of between 1500 and 2500 min^{-1} and a ring of CuAl alloy having a suitably adapted, negative cone shape (Fig. 5) was pressed on in the direction of the arrow 40 with a pressure of between approx. 50 and 250 N/mm^2. By virtue of the considerable heating, the contacting surfaces heat up. As soon as the non-magnetic material (the CuAl alloy; alternatively other alloys, such as an Al alloy for example, are also conceivable) is plastic, the rotating core is stopped and, with an additional compression force (typically 80 to

300 N/mm^2), the two parts are pressed together and thus welded.

Following cooling and undercutting or twisting of the bead produced by the friction welding, a strong, cavity-free and pore-free joint is obtained with a cone geometry which remains virtually unchanged, as can be seen from Fig. 4.

Immediately thereafter, using the same method, the yoke 18 can for example be friction-welded to the assembly consisting of core 14 and intermediate section 16; the result is shown in Fig. 7.

An alternative embodiment is illustrated with reference to Fig. 6. In this case, with a thicker yoke wall diameter, the ring to be used as intermediate element does not have a negative cone contour in the direction of the core 14. At the end, however, the same contour-true joint geometry as shown in Fig. 4 is produced as a result of the process.

It is also not ruled out that, by way of modification to Figs. 5 to 7, for example the intermediate section 16 and/or the yoke section 18 are connected by friction welding as solid material (instead of as tubular material as shown in the figures) and then correspondingly undercut.

The present invention is not restricted to the described embodiments of metallurgical compositions (for instance, in principle, for the friction welding method and as a material for the intermediate section 16, any non-magnetic, metallic or non-metallic material would be suitable - for example plastics or ceramic); different superstructures, procedures or operating parameters are also conceivable.